Studies of Gd-LS at BNL for Reactor Neutrino θ_{13} Measurement

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BNL Neutrino/Nuclear Chemistry Group

Richard Hahn	**Leader, Senior Scientist**
Minfang Yeh	**Associate Scientist**
Zheng Chang	**Research Associate**
Alex Garnov	**Research Associate**
Claude Musikas	**Consultant**
Students…	

BNL Chemistry and Neutrinos

- **HOMESTAKE** Radiochemical Detector

  615 tons of C_2Cl_4; $^{37}Cl + \nu_e \rightarrow {}^{37}Ar + e^-$

- **GALLEX** Radiochemical Detector

  30 tons of Ga; $^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e^-$

- **SNO** Water Cerenkov Detector

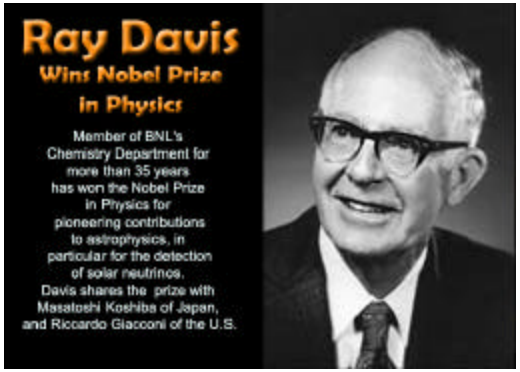
  1000 metric tons of ultra-pure D_2O

- **LENS** Real-time Radiochemical Detector (R&D)

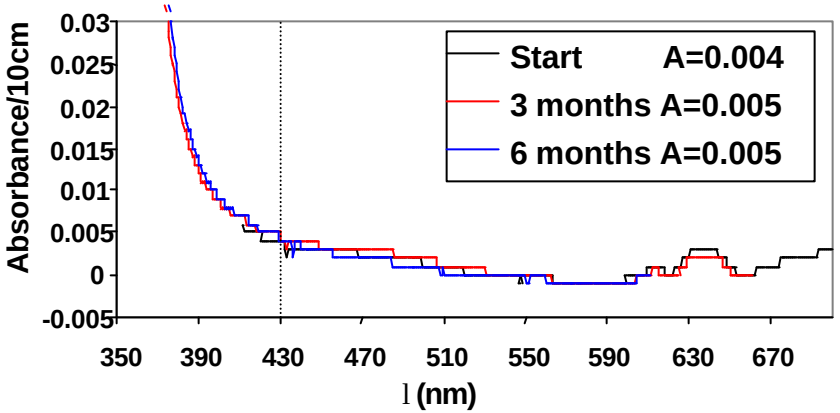
  ^{115}In in Liquid Scintillator

- **BNL-AGS NEUTRINO FACTORY**

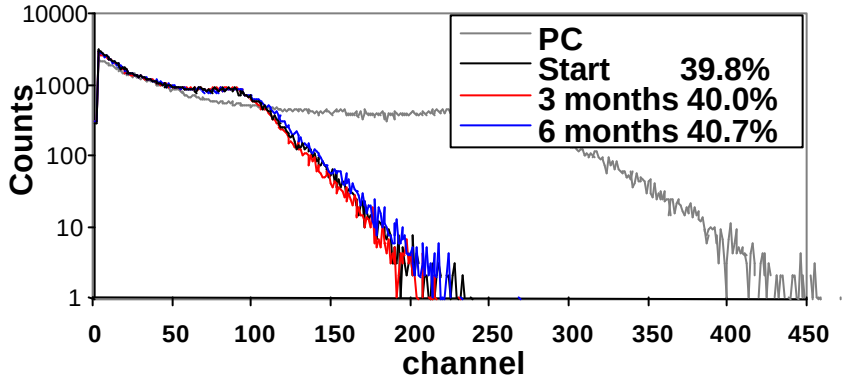
  Very Long-Baseline Experiment- Neutrino Beam from BNL



Characteristics of Bell Labs-BNL In-loaded Scintillator for LENS-Sol



Stability: The UV-VIS absorbance (430 nm) with time over six months (BNL#115, In%=6.77)



Light yield with time over six months (BNL#115, 3g PBD/L , 15mg bis-MSB/L)

BL/BNL developed a very consistent In-LS chemical synthesis method for LENS.

This In-LS has:

- ❑ **high In content (~7%)**
- ❑ **good light yield (~40% of PC)**
- ❑ **long attenuation length (L(1/e) ~9 m without shifter)**
- ❑ **chemical stability for over 6 months since synthesis (top figures).**

The BNL dual-beam, 1-meter optical measurement using blue laser (442nm) confirmed the result from 10-cm UV spectrometer (bottom figure).

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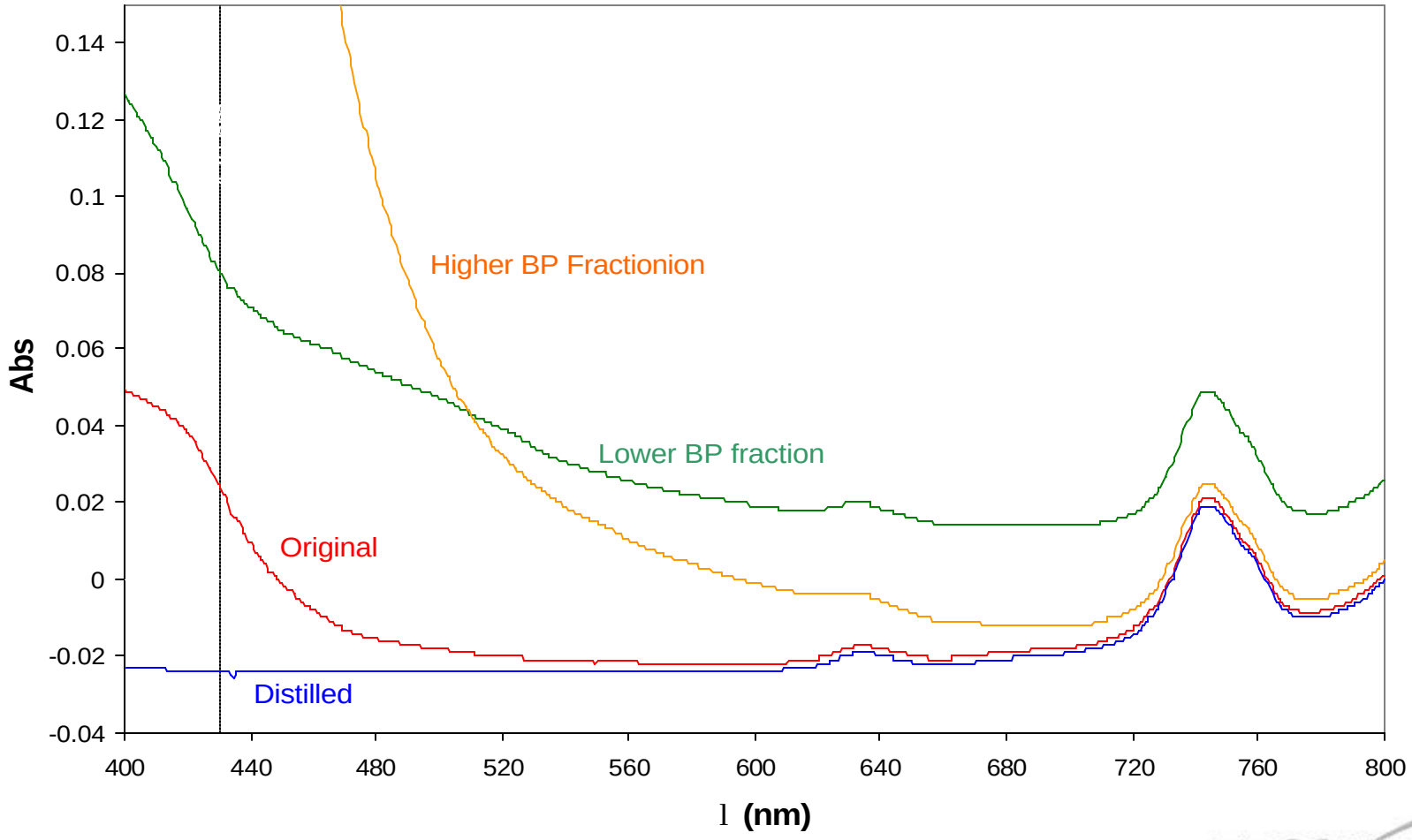
Overview of Gd-LS

- **Needs of Gd-LS**
  - long attenuation length
  - good light yield
  - long-term stability
- **Synthesis of Gd-LS**
  - pH
  - complexing agent
  - equilibrium time
  - purification of chemicals

Purification of HMVA by Distillation



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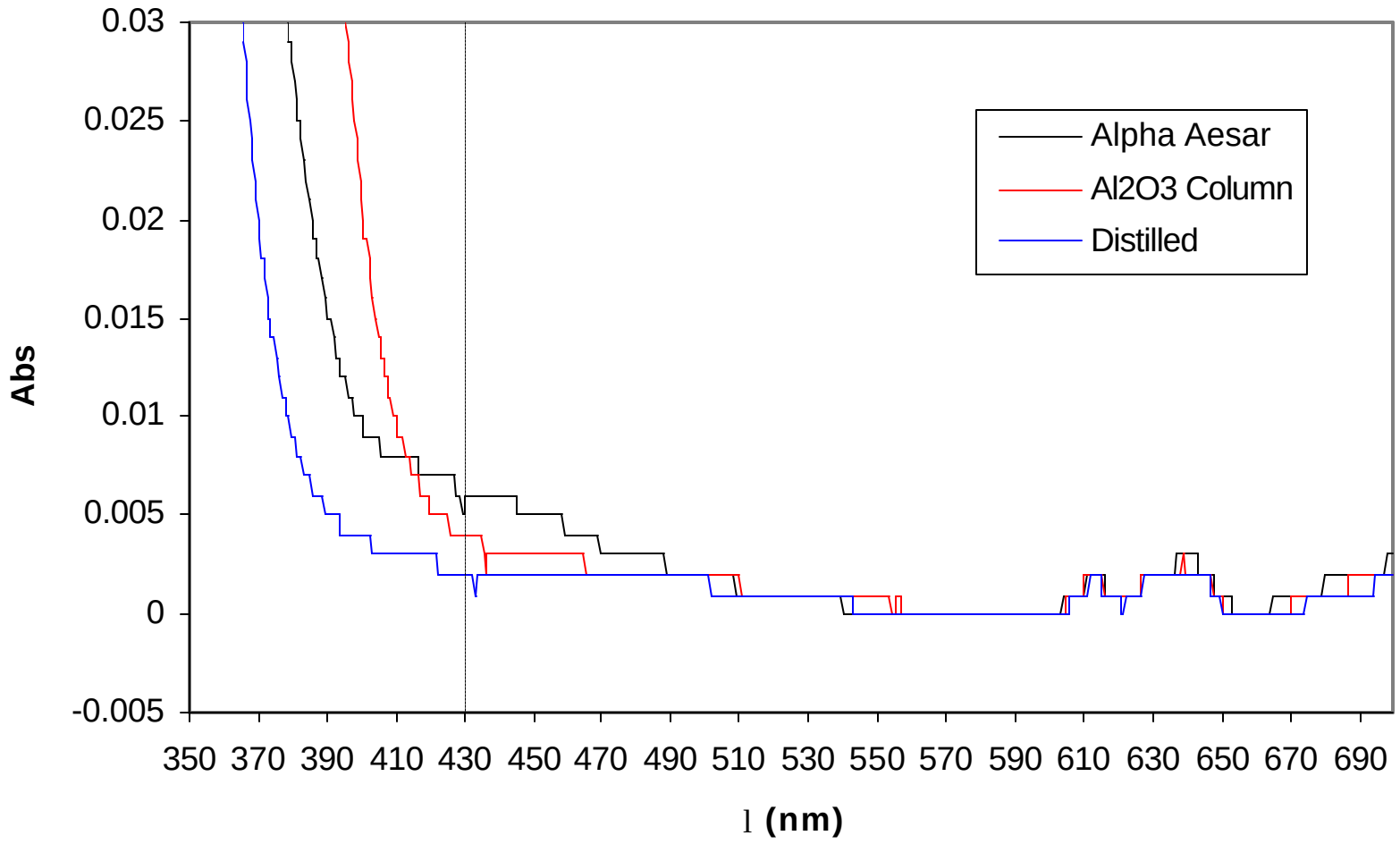
Purification of Pseudocumene, PC



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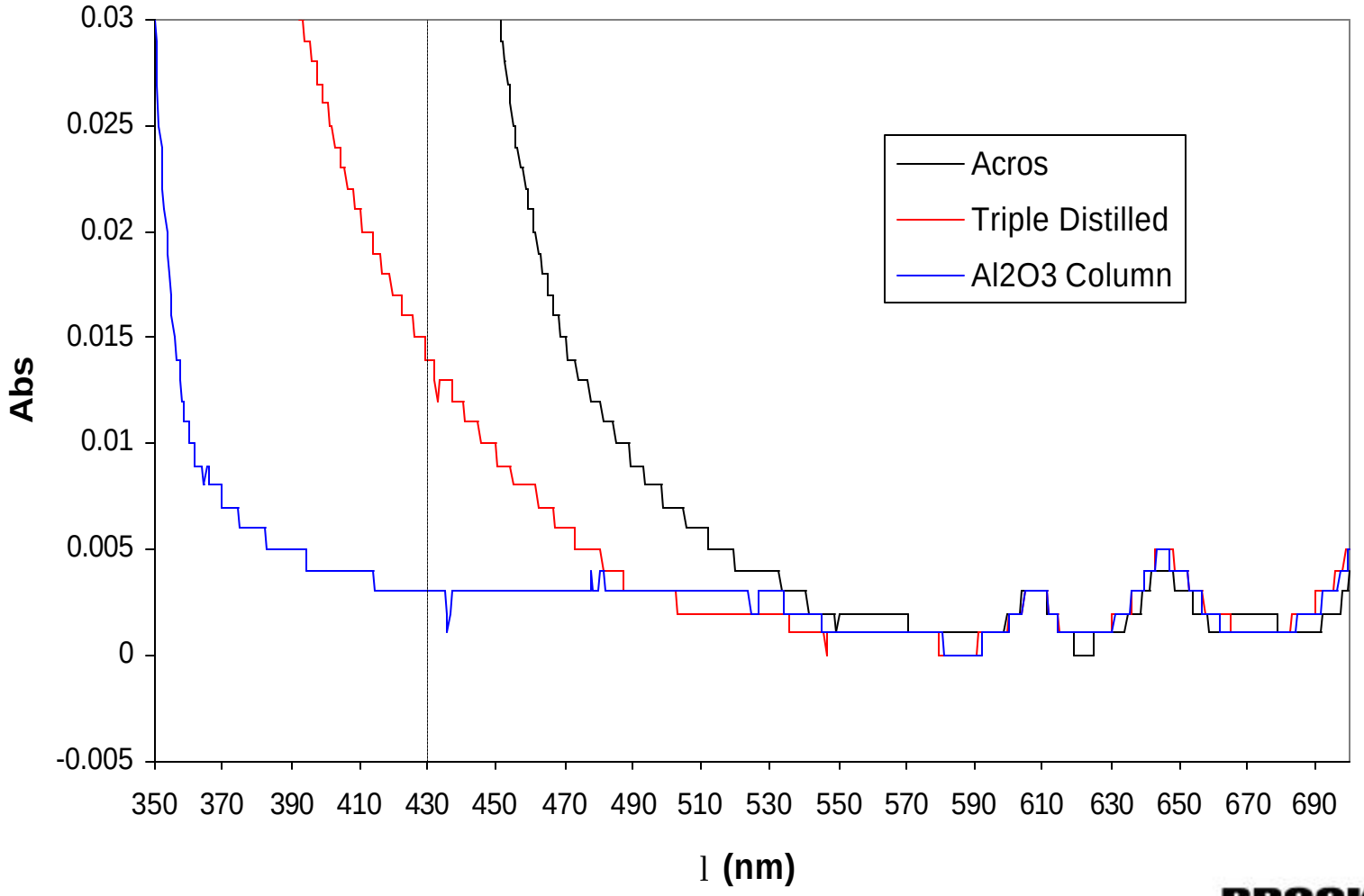
Purification of Phenyl Cyclohexane, PCH



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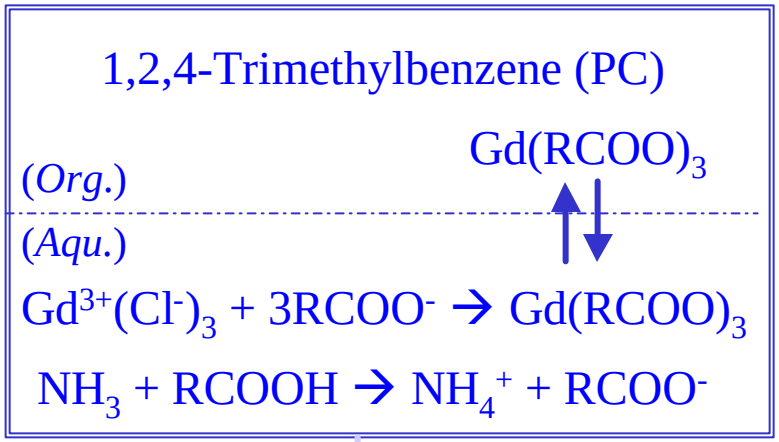
Gd-LS Synthesis and Characterization



Filtration/Separation

Gd-LS

Chemical Analysis

- $L_{1/e}$ by UV-Vis and blue laser.
- Light Yield (S%)
- $[Gd^{3+}]$ by colorimetric method
- $[RCOOH]_{total}$ by acid-base titration
- $[RCOOH]_{free}$ by IR
- $[Gd\ species]_{PC}$ by IR
- $[H_2O]$ by Karl-Fischer titrator
- $[Cl^-]$ by electrochem

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Preliminary

Chemical Composition of BNL 3.24% Gd-LS

	Gd(3+)	MVA	Cl[1]	H_2O	TOPO	PC[2]
wt.%	3.24	6.39	0.23	0.22	1.90	88.07
Number/Gd	1	2.69	0.33	0.59	0.24	35.56

[1] Chlorine content is estimated from the charge balance of the Gd molecule.
[2] PC% is estimated from the percentage of other components.

Analytical formula of Gd in LS:

$$Gd(MVA)_{2.7}Cl_{0.3-x}OH_x(TOPO)_{0.3}$$

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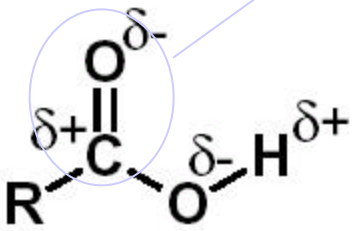
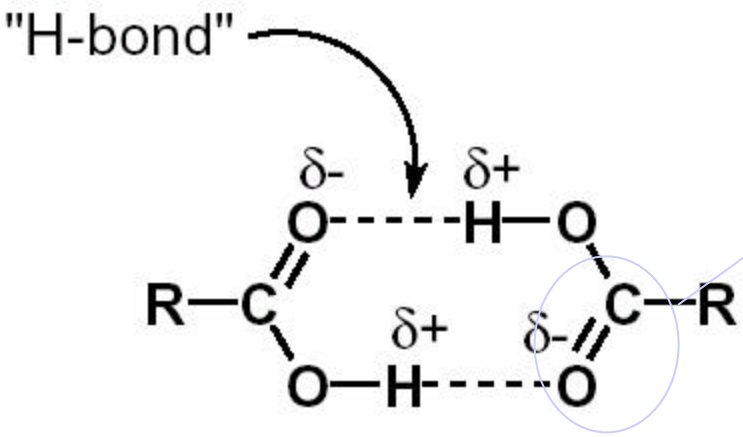
Infrared

Carboxylic Acids - Dimer Formation

In solution carboxylic acids associate through hydrogen bonding



1760 cm^{-1}

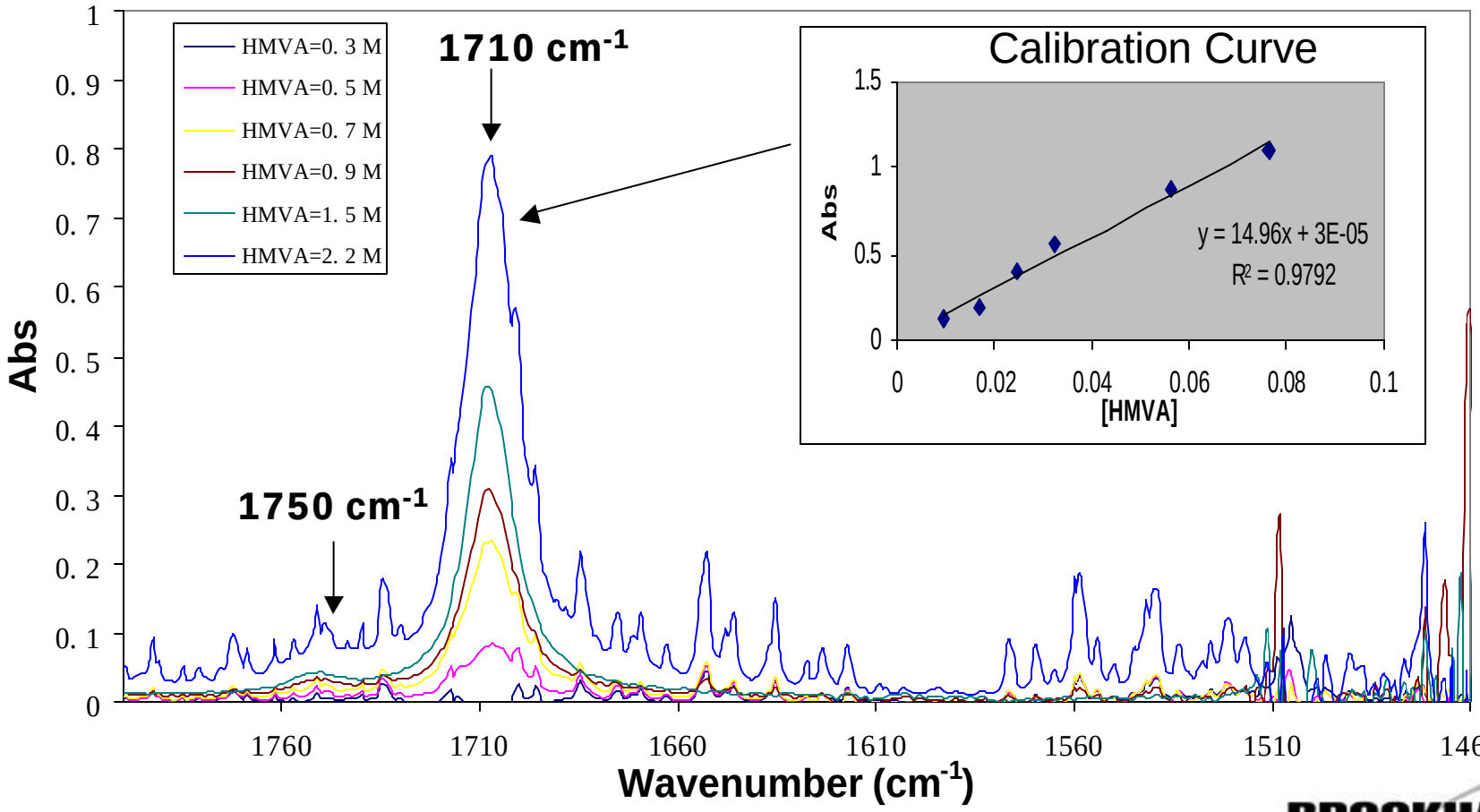


1710 cm^{-1}

C=O stretch => 1725 to 1700 cm^{-1}
very strong

OH stretch => 3000 to 2500 cm^{-1}
very broad & strong

$[HMVA]_{free}$ Estimation



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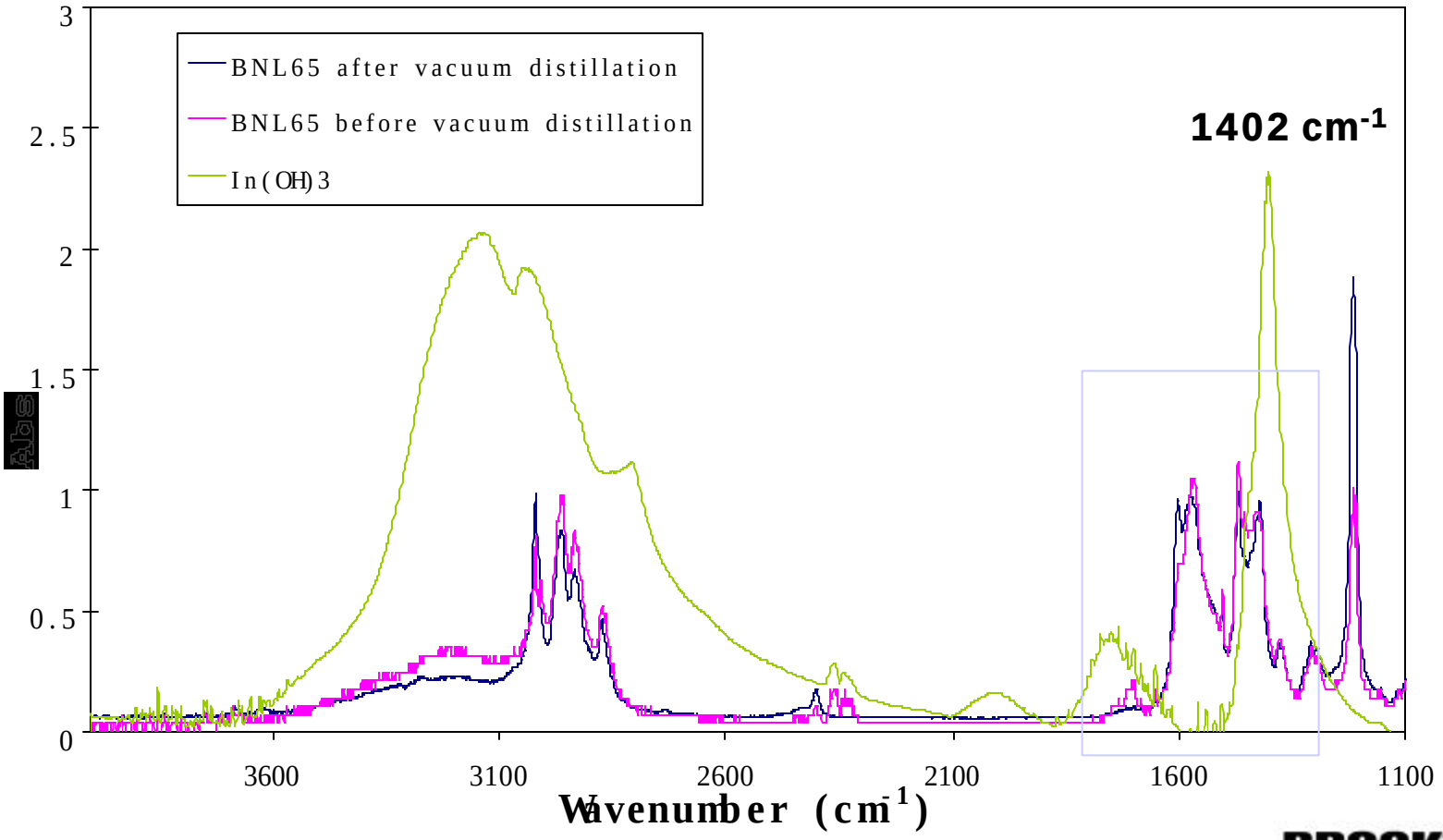
Chemical Species from IR



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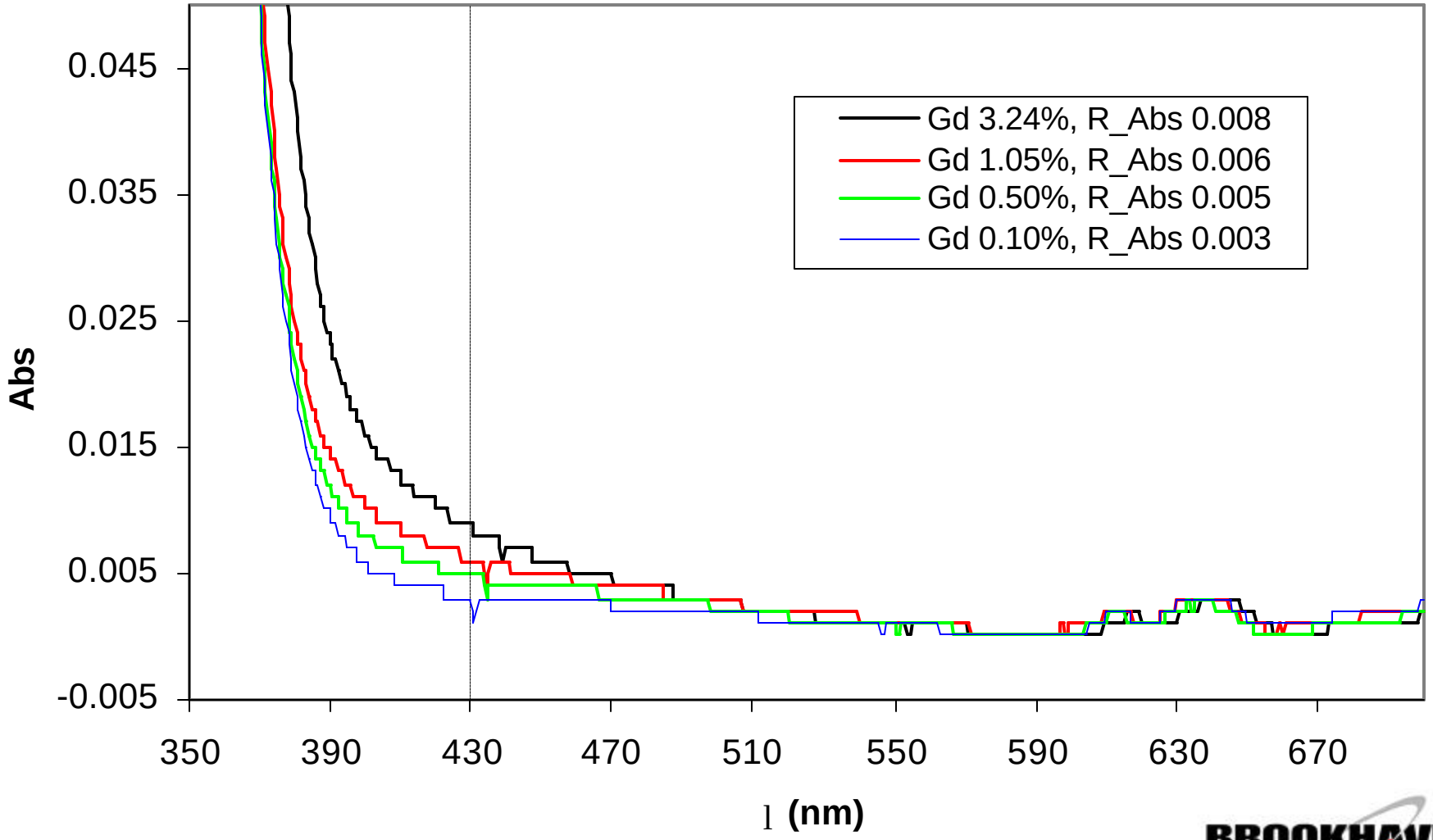
UV Spectra of BNL Gd-LS Samples



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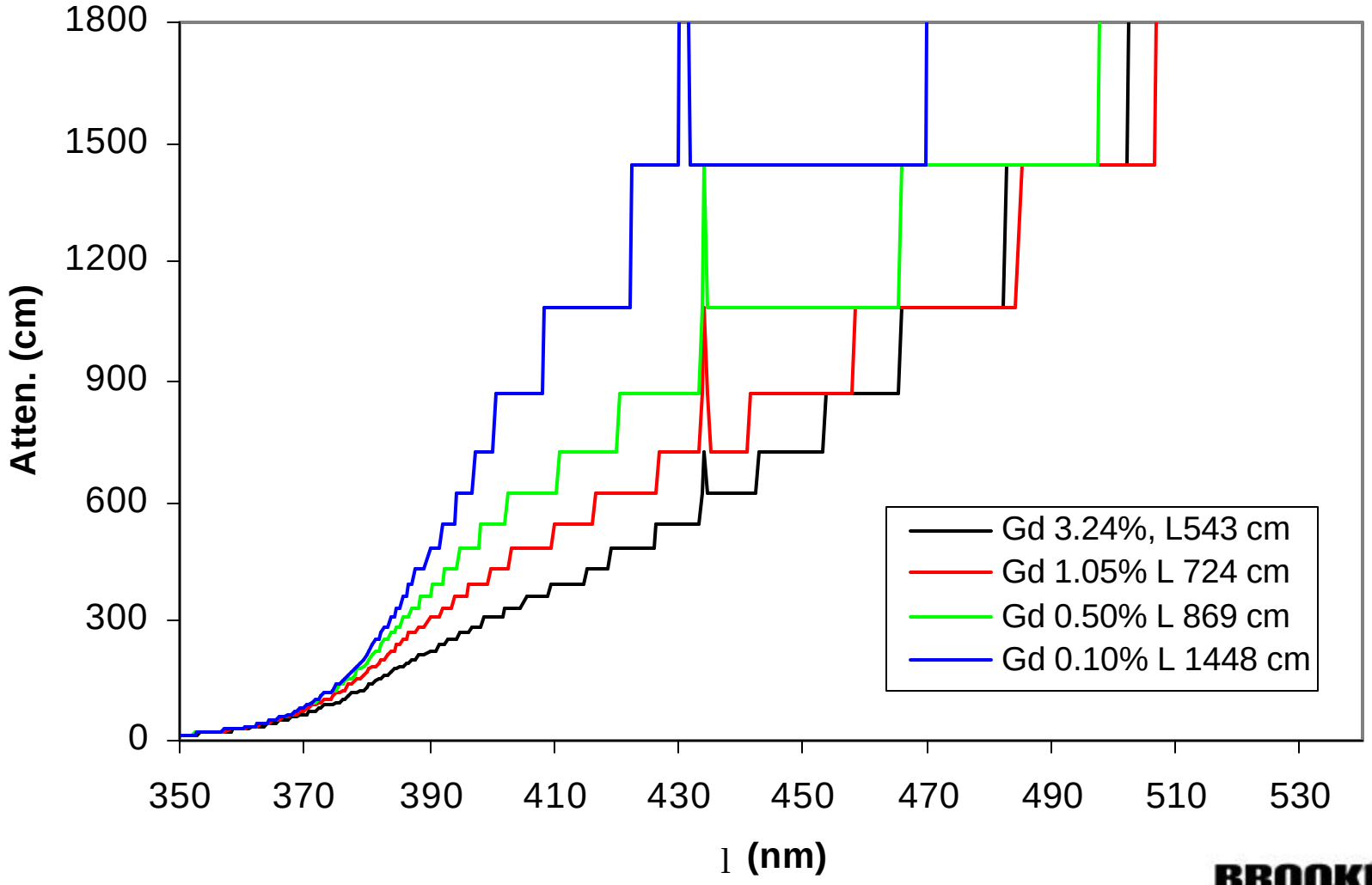
Attenuation Length from UV-Vis

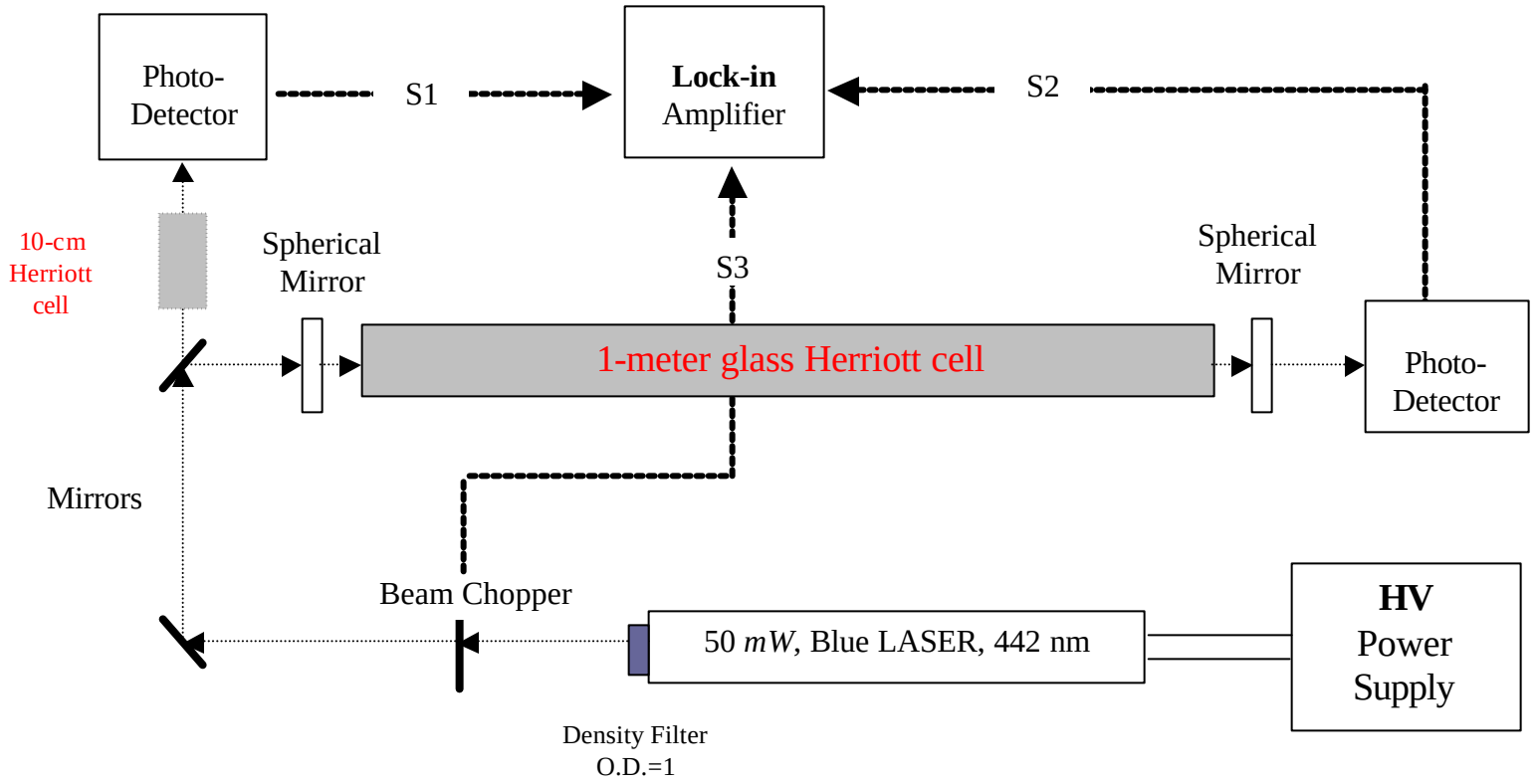
$$L = \frac{\log(e)L}{A(L)}$$

- L is attenuation length
- L is path length = 10 cm at BNL
- A(L) is absolute absorption at 430 nm
- L = (0.434 * 10 cm)/(0.008) = 542 cm = 5.4 m

Attenuation Lengths of BNLGd-LS Samples

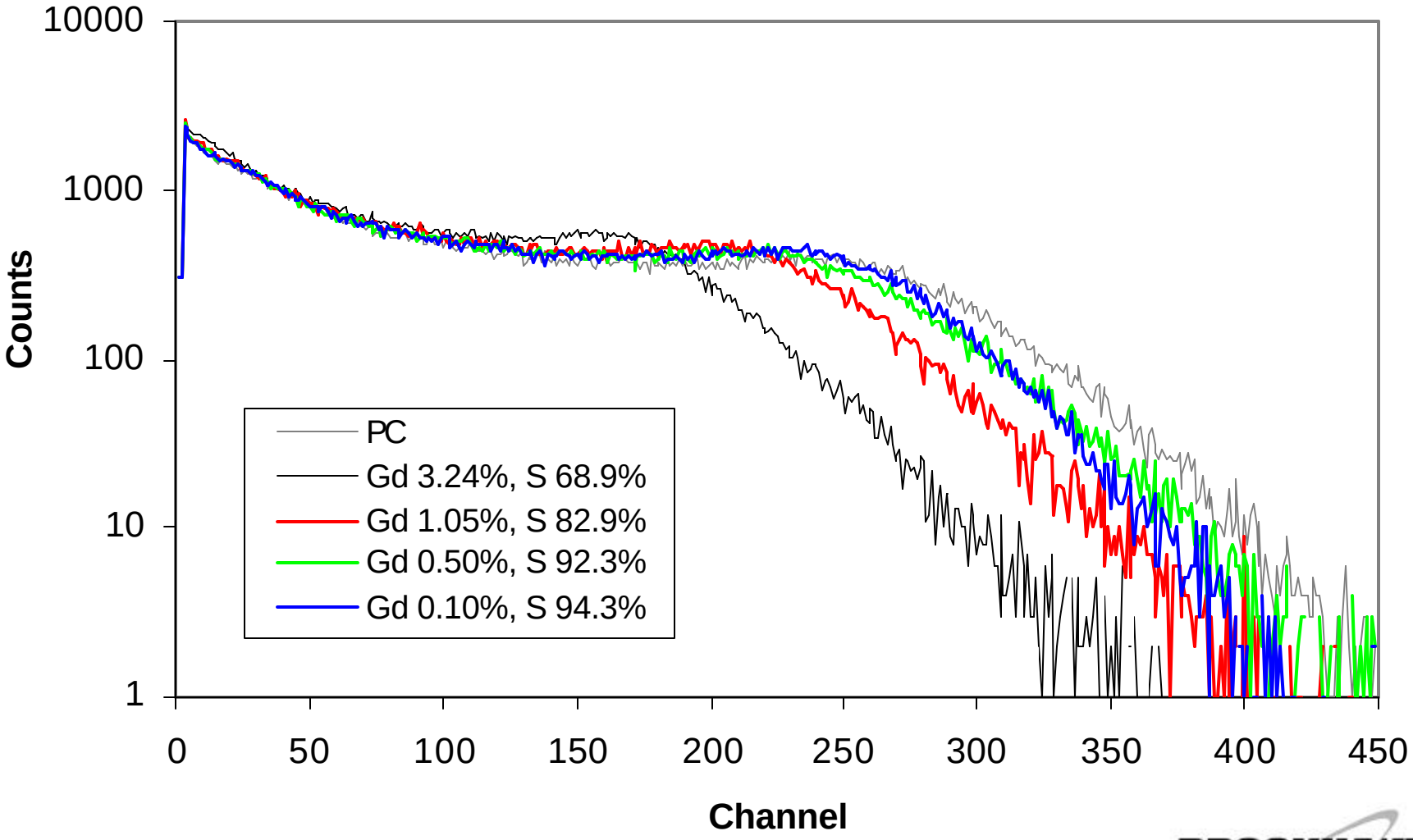


Dual-beam long-path Optic System

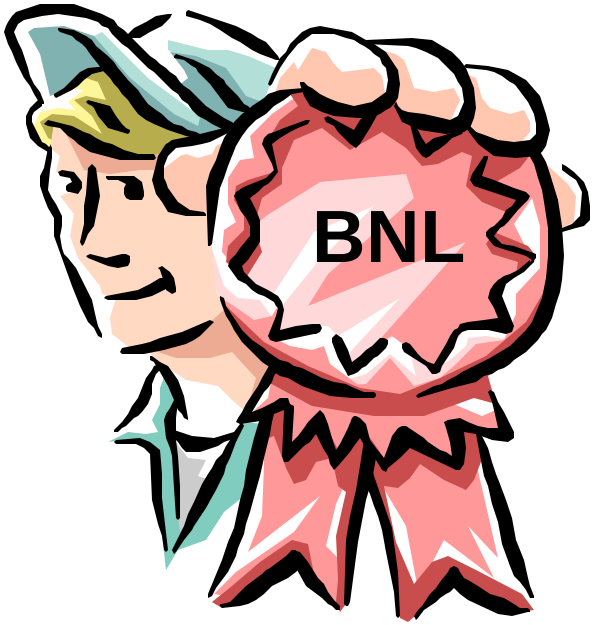


- For In-LS, 1-m laser measurement confirmed the extrapolation from 10-cm UV results.
- S1 – Reference beam for S2 → (S1-S2)

Light Yields of the BNLGd-LS Samples

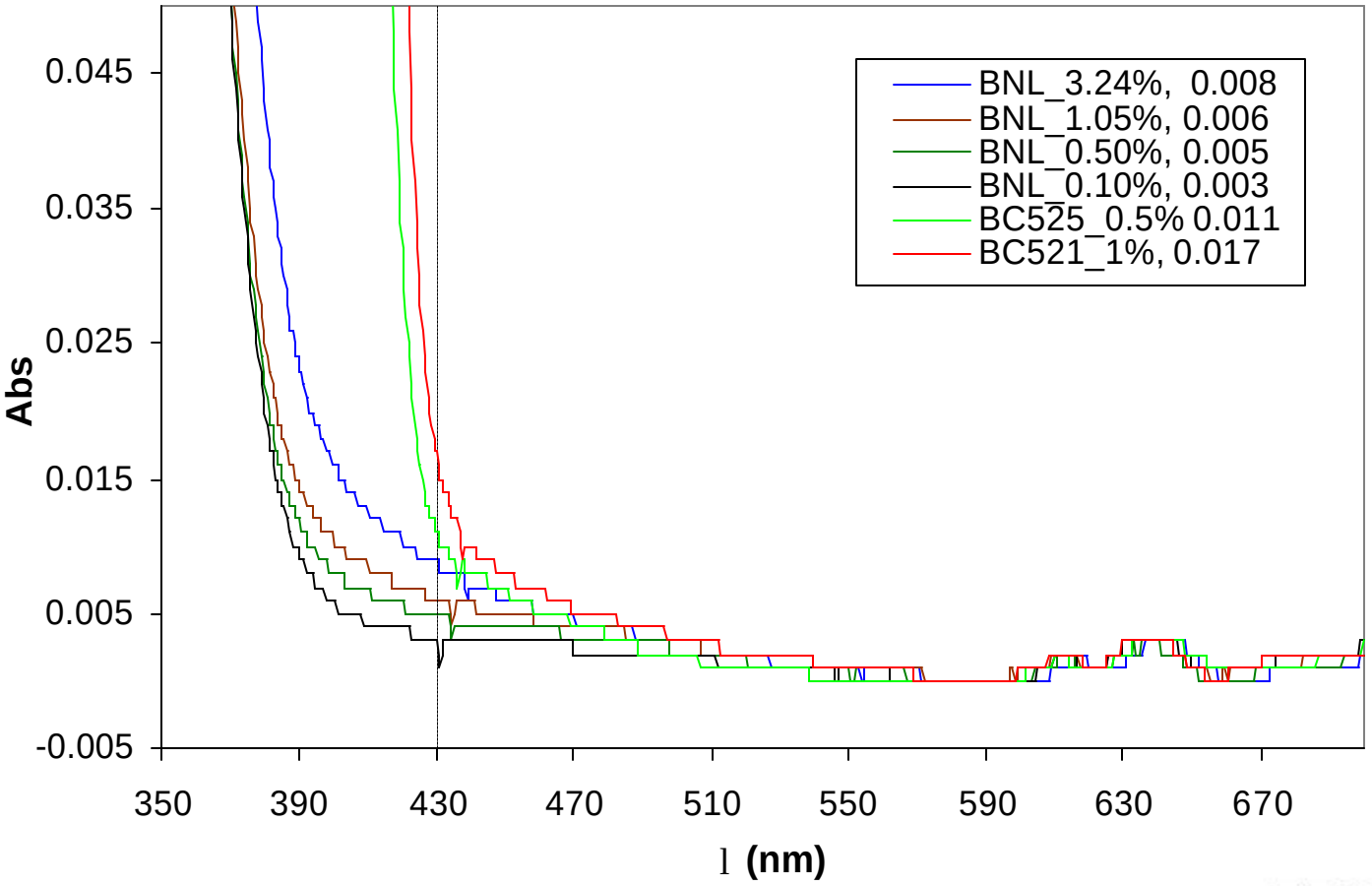


(fluors: 3g PBD/L, 15mg bis-MSB/L)



BNL can produce high quality, Gd-LS sample with good light yield and appropriate attenuation length with adjustable Gd wt% up to ~8%, *but so do others, such as Bicron*…

UV Attenuation of BNL Gd-LS Samples vs Commercials



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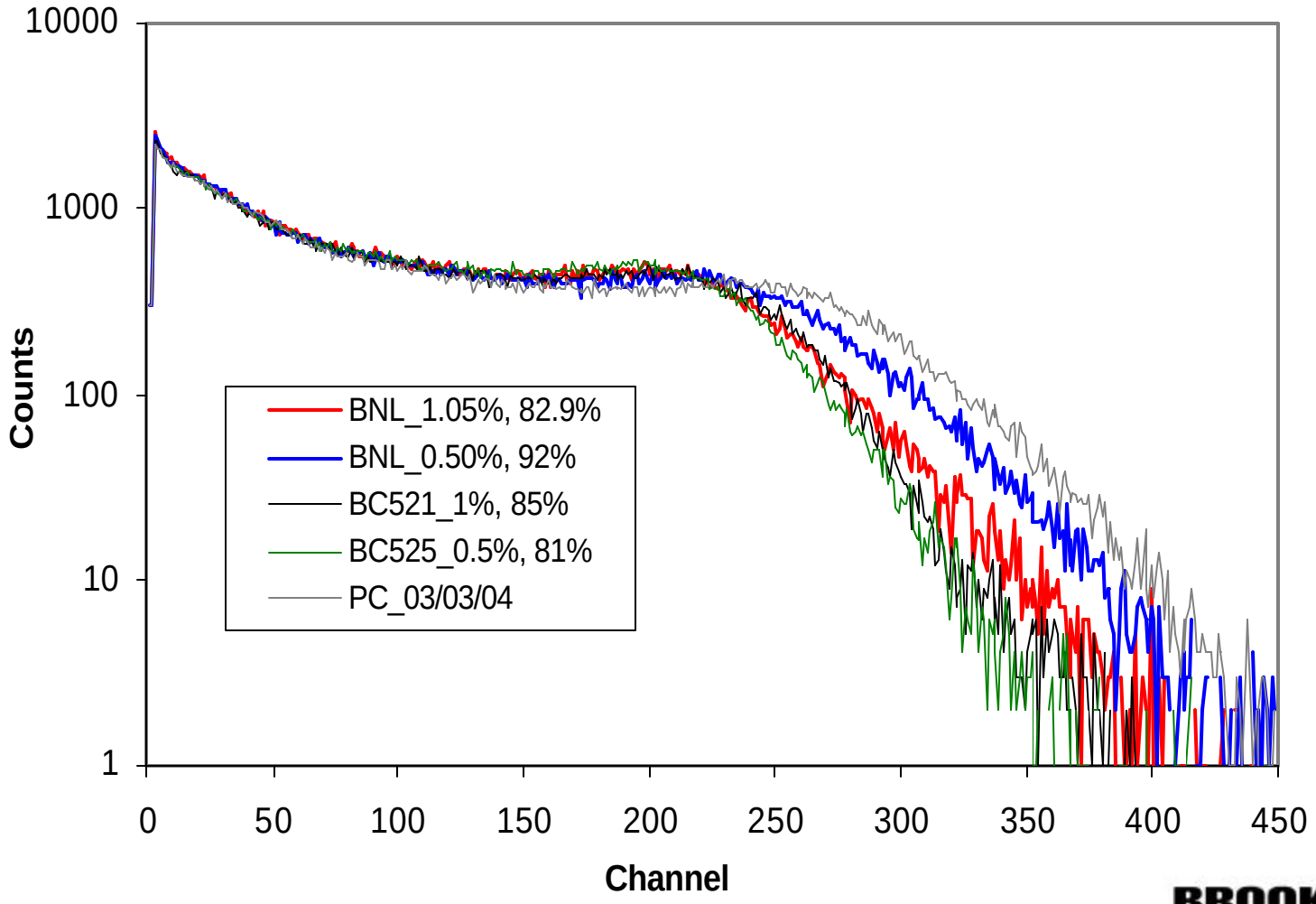
Light Yield of BNL Gd-LS Samples vs Commercials



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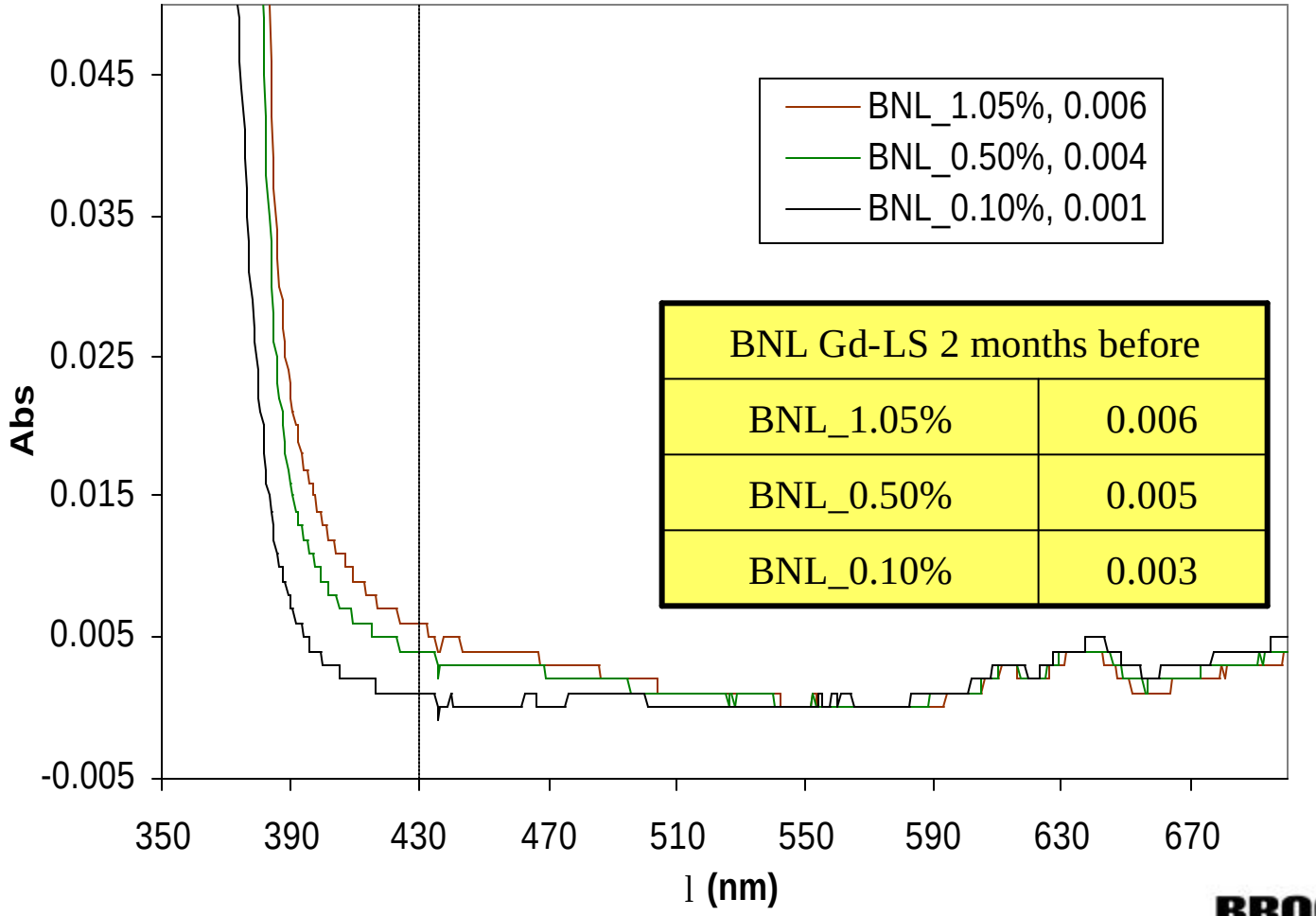
Stability Test: UV Attenuation of BNL Gd-LS after 2 months



BNL Gd-LS 2 months before	
BNL_1.05%	0.006
BNL_0.50%	0.005
BNL_0.10%	0.003

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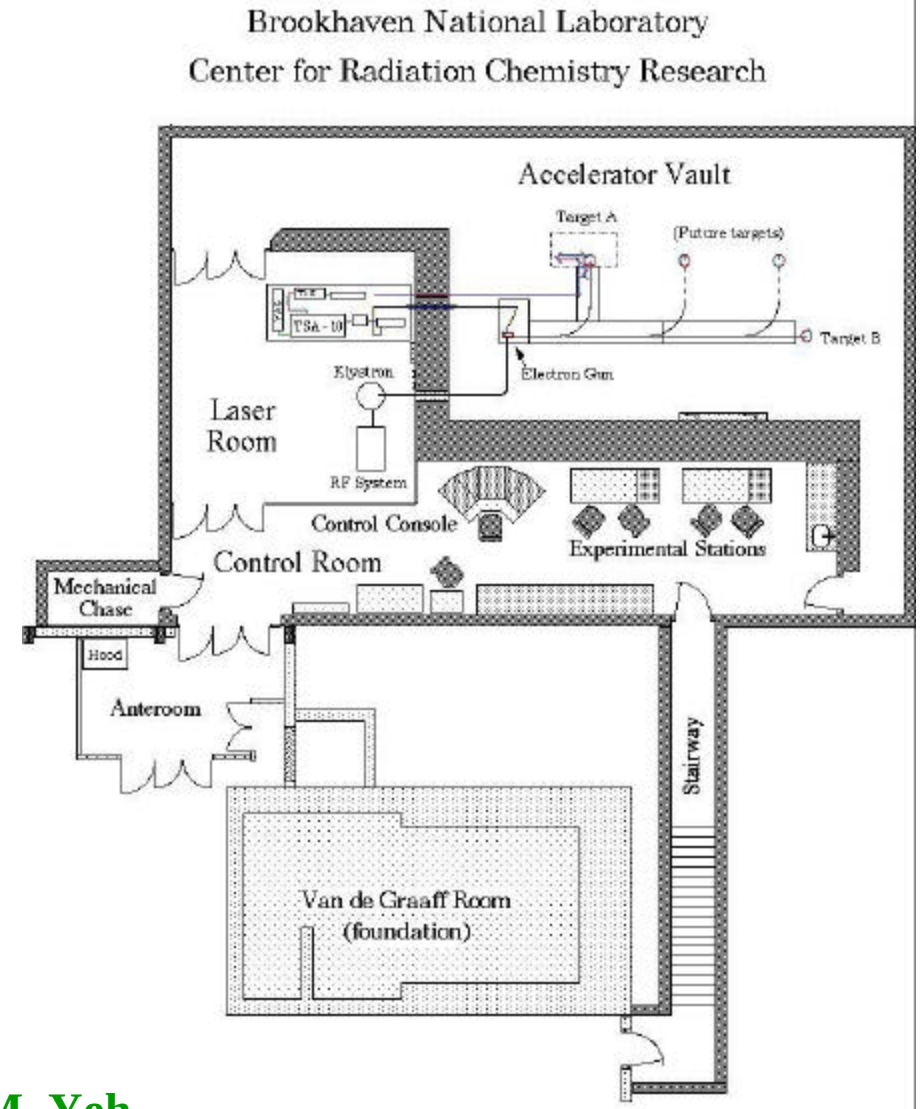
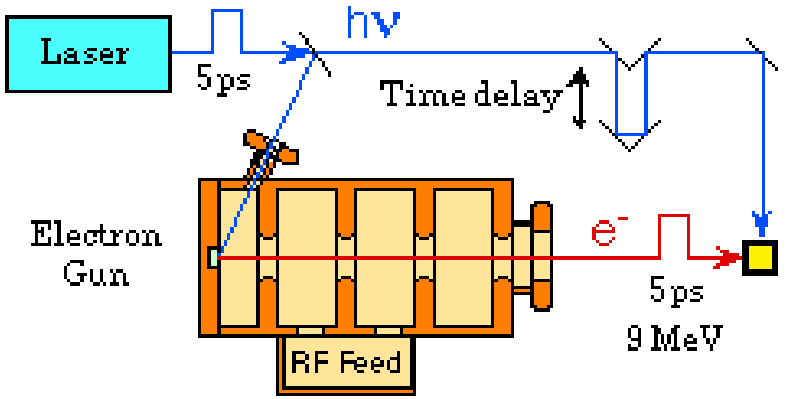
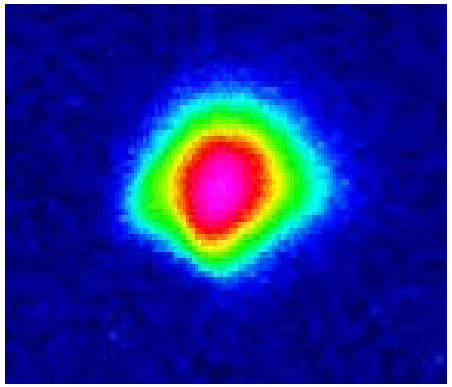
LEAF

Laser Electron Accelerator Facility







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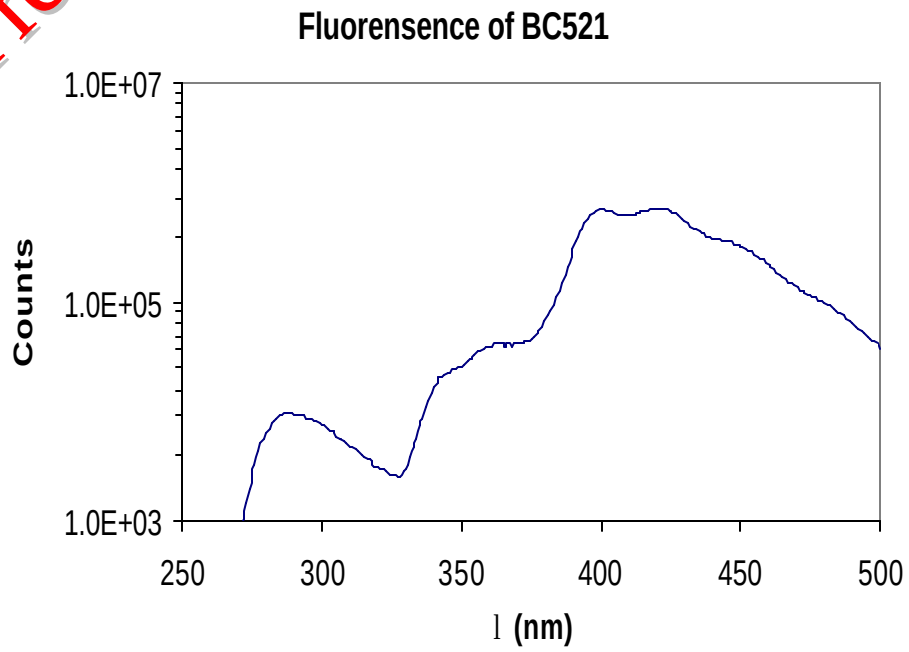
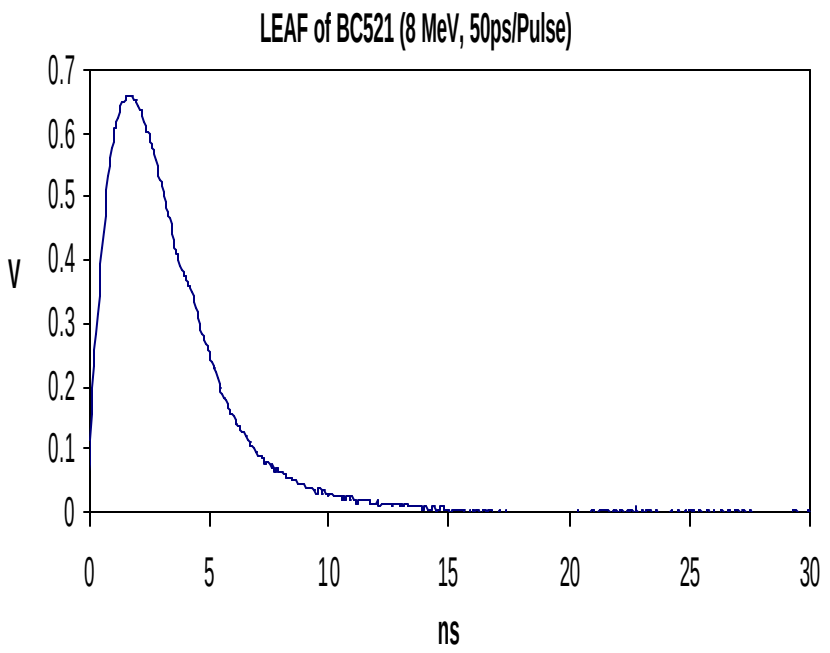
Decay Constant of Gd-LS





	$(Gd\ \%)_w$	W-Shifters	t_d (ns)
BNL	1.0	PBD/bis-MSB	3.64
BC-521	1.0	Yes; N/A	2.81

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BNL vs BC-521

	BNL Gd-LS	BC-521	
Measured by	BNL	BNL	Bicron
Gd %	1%	1%	1%
Attenuation Length (m)	723	255	> 400
Light Yield (s%)	82.9% PC	85.0% PC	57.0% anthracene
Stability	2 months ↑	N/A	long term
Decay Constant (ns)	3.64	2.81	3.6

Ongoing and Future R&D at BNL

- **Vary Synthesis Parameters, e.g., pH, Gd/MVA ratio.**
- **Improve Purification Procedures.**
- **Replace PC with Other LS Solvents, such as PCH.**
- **Quality Control of Long-term Stability: Chemical, Optical, Light Output; Temperature-dependency ("rate approximately doubles per D10^{o} C").**
- **Long-Pathlength Optical Measurements.**